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GB A 2130242 GB 1501655 GB 0707228
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GB 1545300 GB 1482044 EP 0070689
GB 1538364 GB 1457835
"Welding Processes and Technology" by D Romans and E N Simons published by Sir Isaac Pitman and Sons Ltd Chapter 21 at page 167

(58) Field of search
C7F
B3R

(54) Cast iron article surface hardened by plasma arc deposition

(57) A cast iron article 11, such as a cam shaft or rocker arm, is provided with an abrasion resistant integral hardened surface layer containing at least one hardening element chosen from Cr, Mo, Ni, W, V and Nb, the concentration on a weight percentage basis of said hardening element(s) being higher in said hardened layer than beneath said layer by applying a plasma arc (12) to the article surface (11a) and introducing the hardening element(s), in the form of powders (14) of the element(s) or alloys or compounds thereof, into the arc and thus into the molten metal pool (13) formed by the arc on the article surface.

FIG.1

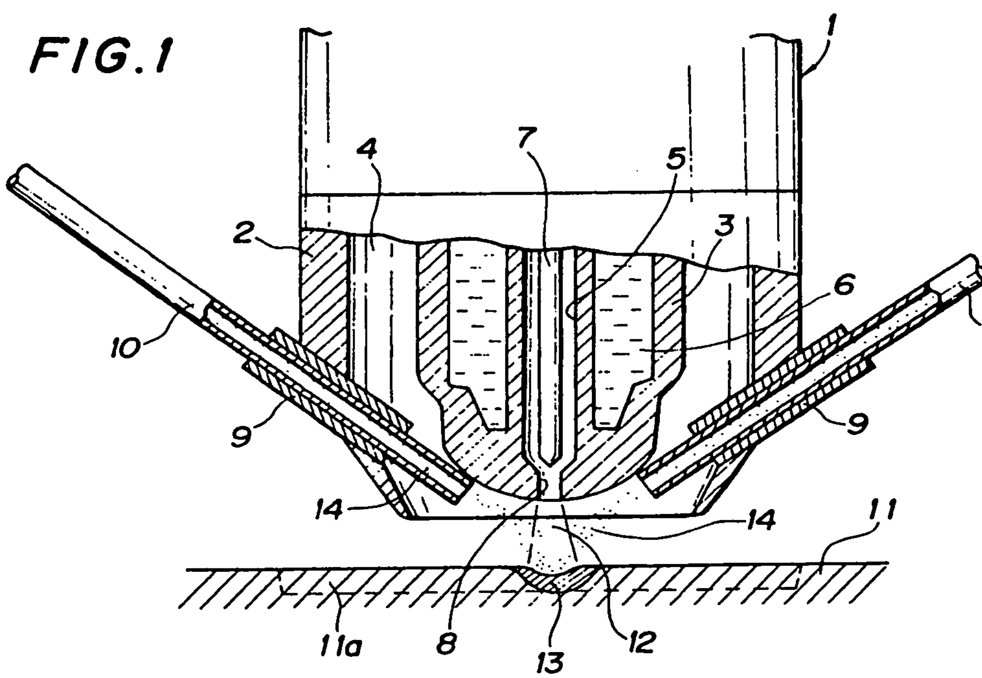

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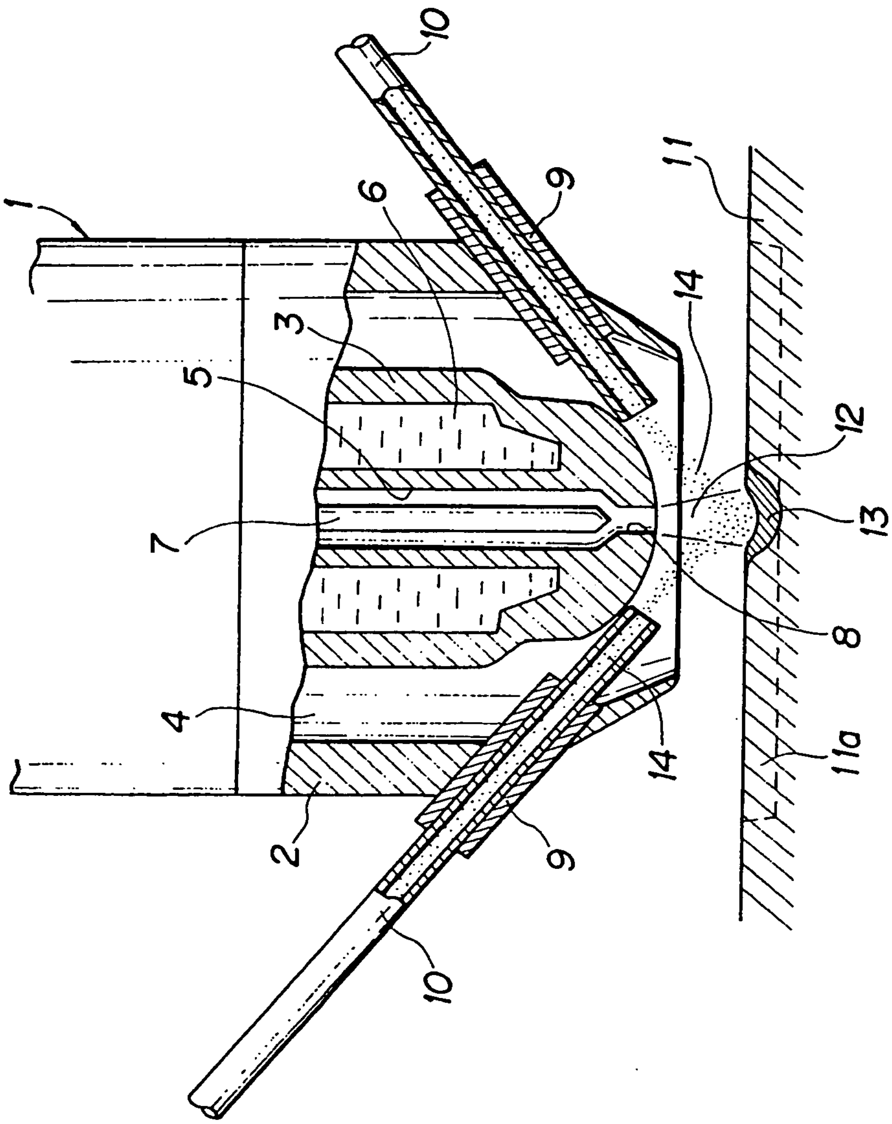
FIG.1



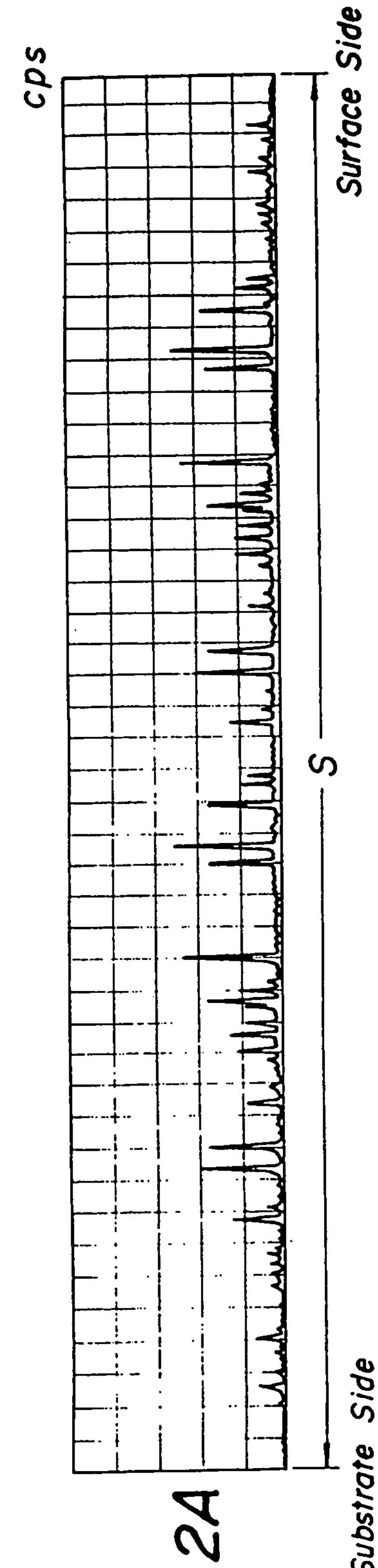


FIG.2A

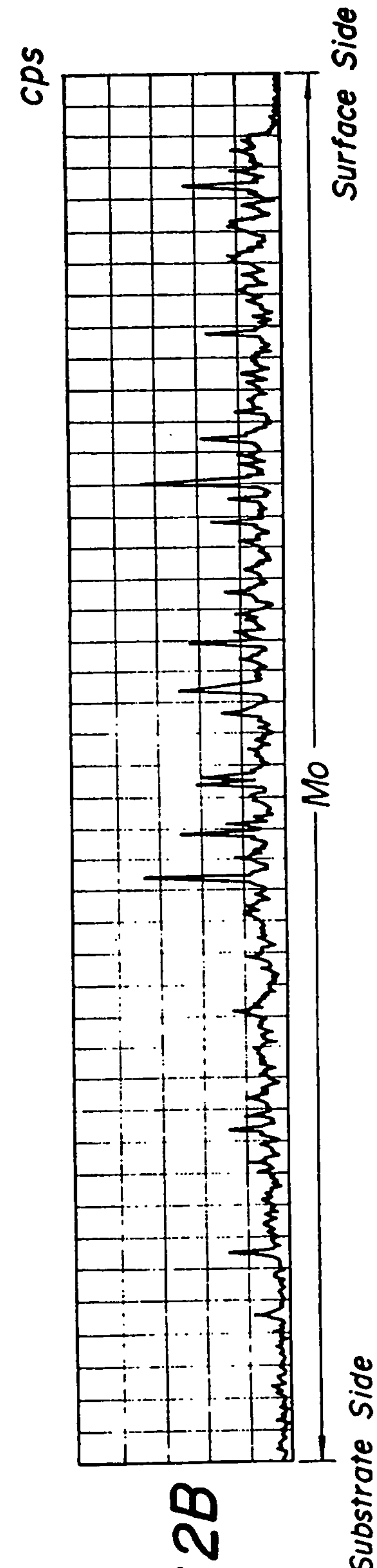


FIG.2B

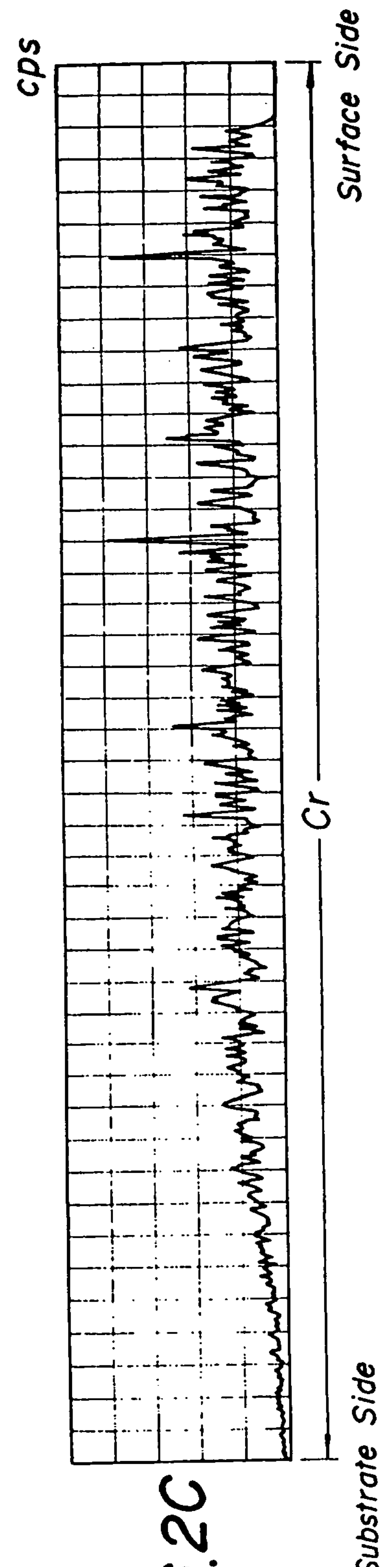


FIG.2C

SPECIFICATION

Cast iron article and method of making same

The present invention relates generally to a cast iron article and a method of making the same. More particularly, the invention relates to a cast iron article having as at least part of the surface an integral hardened surface layer, for example an article such as a cam shaft or a rocker arm for an internal combustion engine which requires part of its surface to be abrasion-resistant, and to a method of making the same.

In an internal combustion engine, the rotation of a crankshaft and the opening and closing actions of valves are inter-related by means of a combination of a cam shaft and a rocker arm, so that the valves are opened and closed in a timed sequence to admit a fuel-air mixture and to exhaust burned gases respectively. The cam shaft and the rocker arm of an OHC (over-head camshaft) type engine are brought directly into slidable contact with each other at certain parts. In an OHV (over-head valve) type engine, a push rod is brought into slidable contact at a part of a tappet thereof with the cam shaft and at another part thereof with a part of the rocker arm and, therefore, both the cam shaft and the rocker arm need a higher abrasion resistance at certain parts of their surfaces than at the remaining parts.

According to a conventional method, in the manufacture of a cast iron article, such as a cam shaft, which needs superior abrasion resistance on part of its surface, a metal of high hardness such as Cr (chromium) or Mo (molybdenum) is added to a melt when casting the article, and a chilling block is set on a part of a metal mould to form concurrently with the casting a chilled layer of high abrasion resistance in the part in contact with the chilling block.

To increase the hardness of the chilled layer to raise further the abrasion resistance, the quantity of the high-hardness metal to be added to the melt may simply be increased. However, this increases the hardness of the article as a whole rather than simply that portion of the article in contact with the chilling block, thus making it difficult to cut or machine the article after the casting. In certain cases, a chilled structure may also be formed in the part not in contact with the chilling block, thus also rendering quite difficult the cutting or machining of the cast article.

For such reasons, to allow subsequent cutting or machining of the article, the proportion of high-hardness metal to be added generally has an upper limit of 1.0 wt% when a single species of high-hardness metal is added or of a total of 1.4wt% in the case of the addition of a plurality of metal species; above these limits the addition of high-hardness metal is detrimental to the performance of the subsequent machining or cutting process. Consequently, in a conventional cast iron article, the abrasion-resistant layer may have relatively poor abrasion resistance.

To overcome such shortcomings, there has already been proposed a method in which, in a casting step, an article is cast in a conventional manner, without adding a high-hardness metal to an extent that would make difficult any cutting or machining of the cast article and without setting a chilling block on a part of the metal mould. In this method (which is disclosed for example in Japanese Patent Application No. 53–115203 (filed on September 21, 1978 and published as Japanese Laid Open Patent Application No. 54–57010 on May 8, 1979) and the equivalent German Patent Application No. P–2742597.4 (filed on September 22, 1974)), after the casting step, that part of the article which is required to be abrasion-resistant is subjected to a hardening treatment.

In the method according to the above-mentioned prior art, an electron beam is irradiated onto the part needing abrasion resistance, to remelt this part; the remelted portion is then left to cool down by itself to form a chilled and relatively hardened layer.

According to this remelt-hardening method, however, the constitution of the chilled layer as finally formed is the same as that of the main body of the cast article and, therefore, no chilled layer so obtained has a particularly excellent hardness or abrasion resistance when compared with the chilled layer formed by using a chilling block.

It is an objective of the present invention to provide a cast iron article having as at least part of the surface an integral surface layer which through having a different chemical composition to the main body of the article is hardened to give good abrasion resistance.

The invention thus provides in one aspect a cast iron article having as at least part of the surface thereof an integral hardened surface layer containing at least one hardening element chosen from chromium, molybdenum, nickel, tungsten, vanadium and niobium, the concentration on a percentage by weight basis of said at least one hardening element in said article being higher in said hardened surface layer than beneath said hardened surface layer.

In the cast iron article of the invention the hardending element is conveniently incorporated as a dispersion or solid solution of the element itself of an alloy or compound of the element.

In a further aspect, the invention provides a method of producing a cast iron article having as at least part of the surface thereof an integral hardened surface layer containing at least one hardening element chosen from chromium, molybdenum, tungsten, vanadium and niobium, said method comprising melting at least part of the surface layer of a cast iron article, introducing

into the melted layer at least one said hardening element in the form of the element or an alloy or compound thereof and resolidifying said melted layer. In the method, the remelting is preferably effected by means of a plasma arc with the at least one hardening element being introduced into the plasma arc in pulverulent form and being carried by the arc into the molten pool of metal formed by the arc on the article's surface.

In a preferred embodiment, the method of the invention comprises the following steps:
(a) setting a predetermined portion of a surface layer of the article opposite a plasms torch;
(b) connecting the article and an electrode of the plasma torch to a positive and a negative terminal respectively of a direct current power source;
(c) discharging a plasma arc from the plasma torch to the predetermined portion of the surface layer to form therein a molten pool while supplying the at least one hardening element in powder form in the plasma arc;
(d) causing the plasma torch to travel over the predetermined portion of the surface layer, while continuing the discharge of the plasma arc and the supply of the powdered hardening element in the plasma arc;
(e) stopping the discharge of the plasma arc and the supply of the powdered hardening element in the plasma arc; and
(f) cooling the molten pool. Thereafter, the article may be removed.

Accordinly, the present invention is able to provide a cast iron article which has as at least part of the surface thereof an integral hardened surface layer markedly excellent in terms of abrasion resistance in comparison with a chilled layer formed using a chilling block.

A preferred embodiment of the invention will now be described by way of example and with reference to the accompanying drawings, in which:—

Figure 1 is a side view, partly in section, of part of a plasma torch as applied to the manufacture of a cast iron article according to the invention; and

Figures 2A, 2B, and 2C are EPMA (electron probe microanalyzer) analysis charts, showing the distribution of the elements sulfur, molybdenum and chromium respectively in a remelt-treated layer of a cast iron article according to the invention.

Referring first to Fig. 1 as a partial sectional view showing the inner structure of a plasma torch 1 adapted for the manufacture of a cast iron article 11 according to the present invention, the plasma torch 1 has, inside a hollowed shield cap 2, a single nozzle 3 made of copper, defining between the cap 2 and the nozzle 3 an axial channel 4 for admitting a shield gas (such as an inactive gas). At the center of the nozzle 3 is formed another axial channel 5 for admitting a working gas (such as argon) which is to be changed into a plasma gas, and, about this channel 5, an end-closed channel 6 through which may be circulated a coolant. A tungsten electrode 7 is provided axially in the working gas channel 5, which channel 5 is reduced at the lower end thereof to define an orifice 8 as a plasma jet hole for discharging the plasma gas.

The shield cap 2 has a plurality of tubular guides 9 passing obliquely therethrough and arranged around the nozzle 3 at an equi-angular pitch, the guides 9 each respectively supporting one of a plurality of powder feed tubes 10 inserted therein and so arranged that an extension of the axis of each tube 10 meets an extension of the axis of the orifice 8.

There will be described below a method for manufacturing the cast iron article 11 according to the present invention, which employs the above-described plasma torch 1.

The cast iron article 11 may initially be an article cast in an ordinary manner, without the addition of any hardening elements to an extent that might interfere with a subsequent cutting process and without the use of a chilling block. Such an article may be cut or machined using conventional processes.

Firstly, as shown in Fig. 1, the plasma torch 1 is set opposite to a predetermined portion 11a, that is, a region required to be resistant to both abrasion and pitching, of a surface layer of the cut cast iron article 11.

Then, the tungsten electrode 7 is connected to a negative terminal (not shown) of a direct current power source (not shown), and the cast iron article 11, to a positive terminal (not shown) of the power source. The shield gas is admitted through the axial channel 4, and the working gas (for example argon) through the axial channel 5. As a result, the electrode 7 discharges, driving the working gas into a plasma state to create the plasma gas, which has a flow path whose area is reduced at the orifice 8 and which rushes out from the orifice in the form of a plasma arc 12, that is a plasma jet of a high temperature and high speed, to be discharged from the nozzle 3. The discharged plasma arc 12 is directed to the predetermined portion 11a of the surface layer of the cast iron article 11 which has a positive potential with respect to the tungsten electrode 7, and with the arc heat there develops a molten pool 13 in the portion 11a.

Concurrently with these operations, in the plasma arc 12, a powder 14 consisting of one or more species of hardening elements is fed through the powder feed tubes 10. The hardening elements are chosen from Cr (chromium), Mo (molybdenum), Ni (nickel), W (tungsten), V (vanadium), Nb (niobium), and the like, and each may suitably be supplied in the form of a

simple substance (e.g the element itself), of an alloy and/or of a compound. Where alloys are used, these may be alloys of two or more of the hardending elements or of one hardening element with one or more other metals. Where compounds are used, these may be sulfides, carbides or the like. The quantity of the powder 14 to be fed in the plasma arc 12 is peferably limited, in terms of the weight proportion of hardening element to molten pool 13, to be from 1.0 to 15.0 wt%, when the number of species of hardening element to be fed is one, or to be from 0.7 to 15.0 wt% for each species and a range of 1.4 to 16.0 wt% in total, when it is more than one. With the use of lower quantities of the powder 14, the portion 11a of the cast iron article 11 as remelt-treated to be partially hardened may not differ significantly in abrasion resistance from that which could be obtained using a conventional chilling process. With the use of higher quantities of powder 14, the hardness of portion 11a may be accompanied by undesired brittleness, resulting in a lowered pitching strength, and cracks may be likely to develop on cooling after the plasma remelting as well as on subsequent grinding.

In the above-described remelt treatment, the powder 14 as fed into the plasma arc 12 is forcibly confined in the arc 12, whereby it is accelerated and heated, and thrown at high speeds and high temperatures onto the surface of the molten pool 13, to be mixed in the pool 13, while the molten pool 13 has a surface area thereof recessed by the pressure of the plasma arc 12 exerted thereon, which recessed area is caused to ripple and run about along with movements of the plasma torch 1, so that the molten pool 13 is effectively stirred. Accordingly, the powder 14 as mixed in the molten pool 13 is evenly distributed therein by the stirring effect. As a result, where the powder 14 has a sufficiently low melting point or is dissolvable in the molten pool 13, it becomes evenly mixed with the substrate of the pool 13, forming an alloy and/or producing a compound. Where the powder 14 is refractory to the pool 13, it becomes evenly dispersed therein, without otherwise changing the chemical composition.

On cooling the molten pool 13, the cast iron article 11 has in the surface portion 11a a remelt-treated layer containing a homogenized alloy with one or more high-hardness metals and/or abrasion-resistant particles evenly dispersed, which remelt-treated layer is thus excellently resistant to both abrasion and pitching.

Various of the operational conditions for the formation of a remelt-treated layer of high abrasion resistance and anti-pitching quality will now be described in further detail.

For carrying the powder 14, a powder carrier gas is passed through the powder feed tubes 10, the flow speed of which gas may preferably be set at 0.5 m/sec or more to confine the powder 14 firmly within the plasma arc 12. With respect to the working gas to be admitted through the axial channel 5, the flow rate may preferably be limited to a range of from 0.3 to 3 l/min; this is greatly reduced from the conventional working gas flow rates used in ordinary plasma-melting, that is 30 to 60 l/min, in order to prevent the powder 14 from being scattered out of the molten pool 13. Moreover, to reduce the working gas flow, the particle size of the powder 14 preferably lies in the range of from 1 to 200 micrometers or, especially preferably, from 1 to 100 micrometers. The arc current, the precise setting of which is dependent on factors such as the material, dimensions, and configuration of the substrate to be remelted (the cast iron article 11), the area and depth to be remelted, the quantity of the powder 14 and the travel speed of the plasma torch 1, is preferably in the range of from 30 to 200 amperes, with the application of a voltage in the range of from 20 to 30 volts.

In the foregoing embodiment of the invention, the powder 14 may contain sulfur, either as elemental sulfur or as a sulfide or a hardening element; in this way the hardening element(s) may be evenly dispersed or dissolved in the form of a sulfide in a remelt-treated layer, thus increasing the lubricating ability, thereby further improving the abrasion resistance. The quantity of sulfur in the powder 14, in terms of a weight proportion of sulfur to the remelt-treated layer, is preferably in the range of from 0.2 to 1.5 wt%. Where the weight proportion is less than 0.2 wt%, the lubricating ability does not become remarkably high and, on the contrary, where it is more than 1.5 wt%, the remelt-treated layer may become brittle, thus lowering the pitching strength.

One or more species of hardening element may conveniently be fed to the molten pool 13, in the form of a ferrous alloy or a carbide.

Figs. 2A, 2B, and 2C are analysis charts plotting the results of an EPMA (electron probe microanalyzer) analysis of a remelt-treated layer formed by the addition of sulfur and, as hardening elements, of elemental chromium and molybdenum. Each of the charts covers a depth region of 1.0 to 1.1 mm from the surface of the remelt-treated layer. As can be seen from the analysis charts, the remelt-treated layer is substantially homogeneous with respect to S, Cr, and Mo.

The following comparative Examples are provided to illustrate further the present invention. In each comparative Example a cast iron article according to the invention is compared in terms of abrasion resistance with a conventional cast iron article.

Example I

A cam shaft for an automobile (an iron casting to FC 30 (grey iron casting, Grade 5) of the JIS (Japanese Industrial Standards), subjected to a rough cutting process) was remelt-treated by remelting the surface of a cam lift portion thereof with a plasma arc, while adding thereto a metal powder of Cr, under the following conditions.

Remelt treatment conditions:

Plasma arc current	85 amperes
Working gas flow	0.3 l/min
Added Cr powder quantity	1.4 g/min
Plasma torch travel speed	1 m/min

The cam lift portion had thereon a layer thus remelt-treated and chill-hardened: this layer was 1.6 mm in depth, was HRC (Rockwell C-scale, JIS) 63 in hardness, and contained substantially homogeneously approximately 13 wt% of Cr. The cam shaft was then finished by grinding a cam part thereof, and was labelled as test piece A.

For comparison, another cam shaft containing 0.9 wt% of Cr in the substrate thereof was cast with only a cam lift portion thereof being chilled by the application of a chilling block. This cam shaft was then also finsished by grinding a cam part thereof, and was labelled as test piece B.

Both test pieces A and B were tested on an actual machine at an engine speed of 1,000 rpm and an oil temperature of 65°C for an operating period of 200 hours. The test results showed a maximum abrasion depth of 25 micrometers for the cam part of test piece A and 105 micrometers for that of test piece B, whereby test piece A was shown to be remarkedly superior in abrasion resistance.

Example II

A cam shaft for a motorcycle (an iron casting to FCD 55 (spheroidal graphite iron casting, Class 3) of the JIS, subjected to a rough cutting process) was remelt-treated by remelting the surface of a cam lift portion thereof with a plasma arc, while adding thereto a powder of Mo_2C of particle sizes within a range of 10 to 50 micrometers, under the following conditions.

Remelt treatment conditions:

Plasma arc current	80 amperes
Working gas flow	0.5 l/min
Added Mo_2C powder quantity	0.3 g/min
Plasma torch travel speed	1.2 m/min

A remelt-treated layer thus obtained was chill-hardened: this layer was 1.8 mm in depth, HRC 57 in hardness and contained 1.5 wt% of Mo. The cam shaft was then finished by grinding a cam part thereof, and was labelled as test piece C.

For comparison, another cam shaft was cast (an iron casting to FCD 55 of the JIS) and chill-hardened. This cam shaft was also finished by grinding a cam part thereof, and was labelled as test piece D.

Both test pieces C and D were tested on an actual machine under conditions analogous to those of Example I. The test results showed a maximum abrasion depth of 80 micrometers for the cam part of test piece C and 120 micrometers for that of test piece D, whereby test piece C was shown to be superior to test piece D in abrasion resistance.

Example III

A cam shaft for an automobile (an iron casting to FC 30, subjected to a rough cutting process) was remelt-treated by remelting the surface of a cam lift portion thereof with a plasma arc, while adding thereto a 50% to 50% by weight mixture of a Cr_3Cr_2 powder and a Mo powder of particle sizes within a range of 2 to 60 micrometers, under the following conditions.

Remelt treatment conditions:

Plasma arc current	80 amperes
Working gas flow	0.5 l/min
Added Cr_3Cr_2 + Mo quantity	0.3 g/min
Plasma torch travel speed	1 m/min

A remelt-treated layer thus obtained on the cam lift portion was chill-hardened: this layer was 1.7 mm in depth, HRC 58 in hardness and contained approximately 0.9 wt% of Mo and approximately 0.8 wt% of Cr. The cam shaft was then finished by grinding a cam part thereof, and was labelled as test piece E.

For comparison, another cam shaft was cast (an iron alloy casting of an FC 30 material containing 0.3 wt% of Mo and 0.6 wt% of Cr) and chill-hardened. This cam shaft was also finished by grinding a cam part therof, and was labelled as test piece F.

Both test pieces E and F were tested on an actual machine under conditions analogous to those of Example I. The test results showed a maximum abrasion depth of 63 micrometers for the cam part of test piece E and 110 micrometers for that of test piece F, whereby test piece E was shown to be extremely superior in abrasion resistance.

Example IV

A cam shaft for an automobile (an iron casting to FC 30, subjected to a rough cutting process) was remelt-treated by remelting the surface of a cam lift portion thereof with a plasma arc, while adding thereto a 65% to 35% by weight mixture of a Cr_3Cr_2 powder and a Mo powder of particle sizes within a range of 2 to 60 micrometers, under the following conditions:

Remelt treatment conditions:

Plasma arc current	80 amperes
Working gas flow	0.5 l/min
Added Cr_3C_2 + Mo quantity	1.6 g/min
Plasma torch travel speed	0.5 m/min

A remelt-treated layer thus obtained on the cam lift portion was chill-hardened: this layer was 1.5 mm in depth, HRC 64 in hardness and contained approximately 5.6 wt% of Mo and approximately 9.4 wt% of Cr. The cam shaft was then finished by grinding a cam part thereof, and was labelled as test piece G.

For comparison, another cam shaft was cast (an iron alloy casting of an FC 30 material containing 0.3 wt% of Mo and 0.6 wt% of Cr) and chill-hardened. This cam shaft was also finished by grinding a cam part thereof, and was labelled as test piece H.

Both test pieces G and H were tested on an actual machine under conditions analogous to those of Example I. The test results showed a maximum abrasion depth of 38 micrometers for the cam part of test piece G and 110 micrometers for that of test piece H, whereby test piece G was shown to be extremely superior in abrasion resistance.

Example V

A cam shaft for an automobile (an iron casting to FC 30, subjected to a rough cutting process) was remelt-treated by remelting the surface of a cam lift portion thereof with a plasma arc, while adding thereto a 50% to 50% by weight mixture of a Cr_3C_2 powder and a MoS_2 powder of particle sizes within a range of 2 to 10 micrometers, under the following conditions.

Remelt treatment conditions:

Plasma arc current	80 amperes
Working gas flow	0.5 l/min
Added Cr_3C_2 + MoS_2 quantity	0.8 g/min
Plasma torch travel speed	0.9 m/min

A remelt-treated layer thus obtained on the cam lift portion was chill-hardened: this layer was 1.6 mm in depth, HRC 63 in hardness and contained, approximately, 3.4 wt% of Mo, 4.8 wt% of Cr, and 0.82 wt% of S. The cam shaft was then finished by grinding a cam part thereof, and was labelled as test piece I.

For comparison, another cam shaft was cast (an iron alloy casting of an FC 30 material containing 0.3 wt% of Mo and 0.6 wt% of Cr) and chill-hardened. This cam shaft was also finished by grinding a cam part thereof, and was labelled as test piece J. (The chemical composition of test piece J was the same as that of test piece F of Example III).

Both test pieces I and J were tested on an actual machine under conditions analogous to those of Example I. The test results showed a maximum abrasion depth of 26 micrometers for the cam part of test piece I and 110 micrometers for that of test piece J, whereby test piece I was shown to be extremely superior in abrasion resistance.

As will readily be understood from the foregoing description, a cast iron article such as a cam shaft or a rocker arm treated according to the invention has newly formed in a predetermined portion of a surface layer thereon an integral hardened surface layer containing one or more species of hardening element such as Cr and Mo preferably substantially evenly dispersed or dissolved therein, thus resulting in no more than that predetermined portion of the surface layer being hardened to a high degree, while leaving the rest of the article and its surface at a sufficiently low hardness to facilitate subsequent machining or cutting work. Therefore, according to the invention, there can be achieved a cast iron article which is not only superior at a particular surface portion in both abrasion resistance and anti-pitching quality, but is also excellent as a whole in its cutting and maching workability. Moreover, by adding sulfur besides such hardening elements, the abrasion resistance can be enhanced still more.

It will be easily understood that the present invention may be applied to any cast iron article needed, at a surface part, to be abrasion resistant and, in the remaining parts, to have a good workability such as ease of machining or cutting.

CLAIMS

1. A cast iron article having as at least part of the surface thereof an integral hardened surface layer containing at least one hardening element chosen from chromium, molybdenum, nickel, tungsten, vanadium and niobium, the concentration on a percentage by weight basis of said at least one hardening element in said article being higher in said hardened surface layer than beneath said hardened surface layer.

2. An article as claimed in claim 1 wherein said integral hardened surface layer comprises a remelted portion of the surface layer of said article.

3. An article as claimed in either of claims 1 and 2 wherein said at least one hardening element is incorporated in said integral hardened surface layer as a dispersion or solid solution of the element or an alloy or a compound thereof.

4. An article as claimed in any one of claims 1 to 3 wherein said integral hardened surface layer contains one of said hardening elements, that hardening element being present in said layer at from 1.0 to 15.0 wt%.

5. An article as claimed in any one of claims 1 to 3 wherein at least two of said hardening elements are present in said integral hardened surface layer wherein each of said at least two hardening elements is present in said layer at from 0.7 to 15 wt% and wherein all of said at least two hardening elements are present in said layer at, in total, from 1.4 to 16.0 wt%.

6. An article as claimed in any one of claims 1 to 5 wherein at least one said hardening element is included in said integral hardened surface layer as a sulfide.

7. An article as claimed in claim 6 wherein the proportion of sulfur in said sulfide to said integral hardened surface layer is from 0.2 to 1.5 wt%.

8. An article as claimed in any one of claims 1 to 7 wherein at least one said hardening element is included in said integral surface layer as a carbide.

9. An article as claimed in any one of claims 1 to 8 in the form of a cam shaft for an internal combustion engine, and wherein said integral hardened surface layer is formed on a cam surface of said cam shaft.

10. An article as claimed in any one of claims 1 to 8 in the form of a rocker arm for an internal combustion engine, and wherein said integral hardened surface layer is formed on a cam-follower surface of said rocker arm.

11. An article as claimed in any one of the preceding claims wherein said integral hardened surface layer is formed by melting a surface layer of the article and introducing said at least one hardening element into the melted layer.

12. A cast iron article having a partially hardened surface substantially as herein described with reference to the test pieces A, C, E, G and I of the Examples.

13. A method of producing a cast iron article having as at least part of the surface thereof an integral hardened surface layer containing at least one hardening element chosen from chromium, molybdenum, tungsten, vanadium and nobium, said method comprising melting at least part of the surface layer of a cast iron article, introducing into the melted layer at least one said hardening element in the form of the element or an alloy or compound thereof and resolidifying said melted layer.

14. A method as claimed in claim 13 comprising the steps of:

(a) setting a predetermined portion of a surface layer on a cast iron article opposite to a plasma torch;

(b) connecting said article and an electrode of said plasma torch to a positive terminal and a negative terminal respectively of a direct current power source;

(c) discharging a plasma arc from said plasma torch to said predetermined portion of said surface layer to form therein a molten pool while supplying said at least one hardening element in powder form in said plasma arc;

(d) causing said plasma torch to travel over said predetermined portion of said surface layer, while continuing the discharge of said plasma arc and the supply of said hardening element to said plasma arc;

(e) stopping the discharge of said plasma arc and the supply of said hardening element to said plasma arc; and

(f) cooling said molten pool.

15. A method as claimed in claim 14 wherein the working gas for said plasma arc is supplied at a rate of from 0.3 to 3 l/min.

16. A method as claimed in either of claims 14 and 15 wherein the voltage and the amperage for creating said plasma arc are from 20 to 30 volts and from 30 to 200 amperes respectively.

17. A method as claimed in any one of claims 14 to 16 wherein said at least on hardening element in powder form is supplied at a rate of from 0.3 to 1.6 g/min, and wherein said plasma torch has a travel speed of from 0.5 to 1.2 m/min.

18. A method as claimed in any one of claims 13 to 17 wherein said at least one hardening element is supplied in the form of a powder of the element, of an alloy, of a carbide or of a sulfide.

19. A method as claimed in any one of claims 13 to 18 wherein said at least one hardening element is supplied in the form of a powder having a particle size of from 1 to 200 micrometers.

20. A method as claimed in any one of claims 13 to 19 wherein said at least one hardening element is supplied in a carrier gas having a flow rate of at least 0.5 m/sec.

21. A method, substantially as herein described with reference to the drawings and to test pieces A, C, E, G and I of Examples, for producing a cast iron article having an integral hardened surface layer.

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